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Title: Fast gateable electron gun

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Intended for: To use as a basis of discussion with vacuum tube manufacturers as with other laboratories interested in possible modification to existing high power klystron designs to allow for new FEL applications that require short duration high pulse repetition rates

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Fast Gateable Electron Gun Options for High Peak Power Accelerator Klystrons

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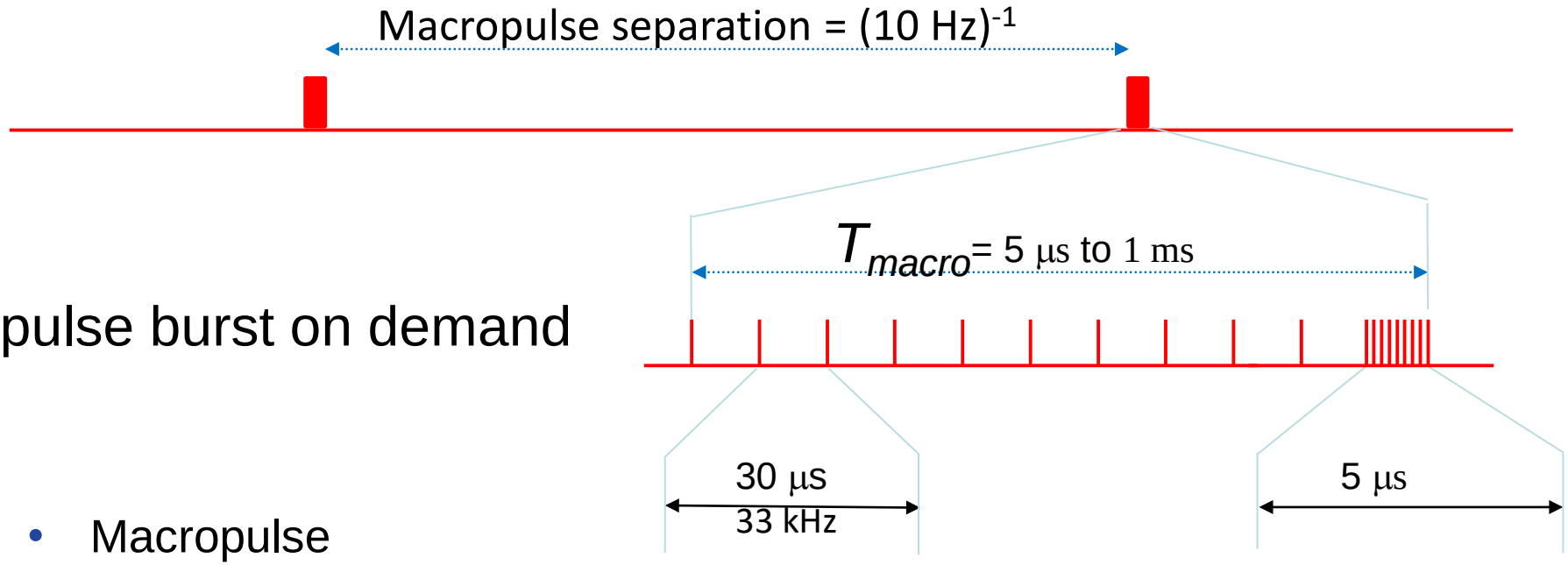
FEL Requirements
Pulse Width and Duty Factor



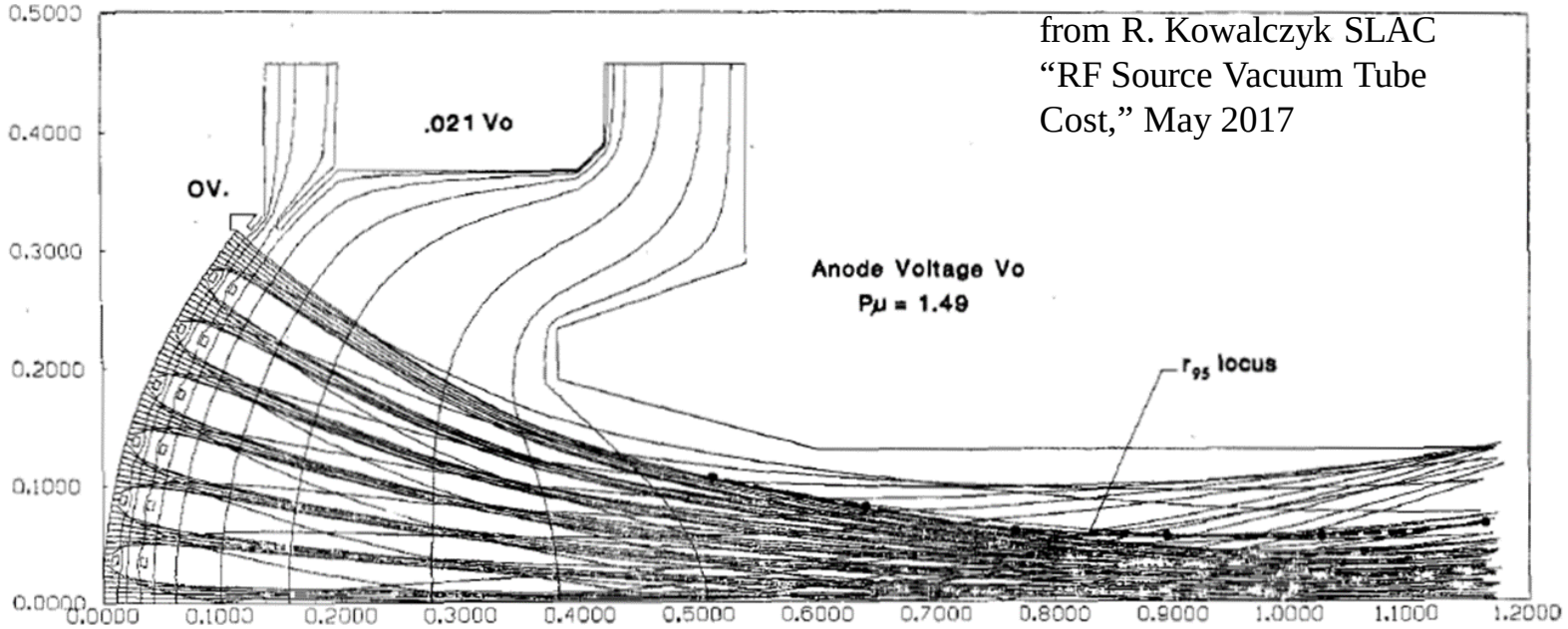
pulse burst on demand

- Macropulse
  - 30 each 0.6 μs RF pulses over 1 ms
  - Includes single “on-demand” 5 μs pulse
- Macropulse rep rate 10 Hz
- Average duty: 23 μs x 10 Hz = 0.02%

Limitations of Existing Technology

- Toshiba E37212 C-band Klystron
  - 50 MW peak at 5.712 GHz
  - 3 µsec RF pulse width @ 100 Hz = 0.03% duty
  - Diode, cathode pulsed electron gun; E_k = 370 kV, I_k = 344 A
  - The 127 MW peak beam power limits klystron operation to very short pulses and low duty
- The ½CV^2 energy required to switch the electron gun on and off practically limits rise time and modulation rate
- **A triode gun, with a low voltage non-intercepting modulating electrode, is needed to provide the rapid, on-demand pulse formats required for new FEL applications**

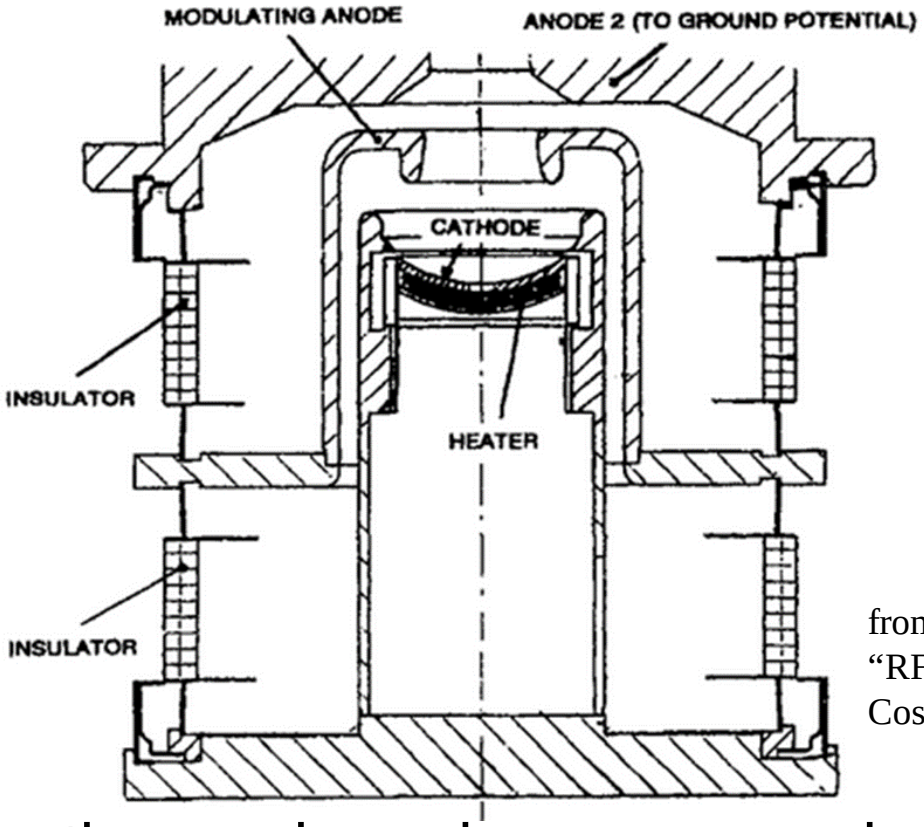
Triode Gun Grids



from R. Kowalczyk SLAC "RF Source Vacuum Tube Cost," May 2017

- Control grid directly in front of the cathode requires the least amount of modulation voltage
- Widely used at lower power but unlikely to survive long at the voltage and current required for 50 MW klystrons

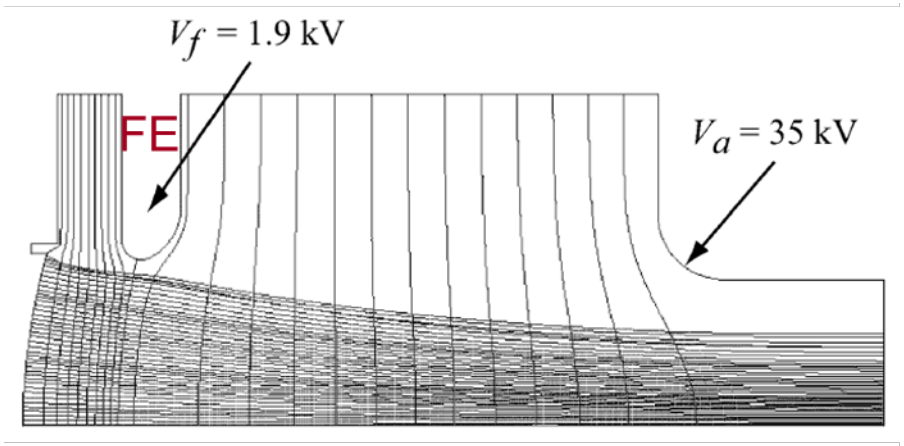
Triode Gun
Modulating Anode



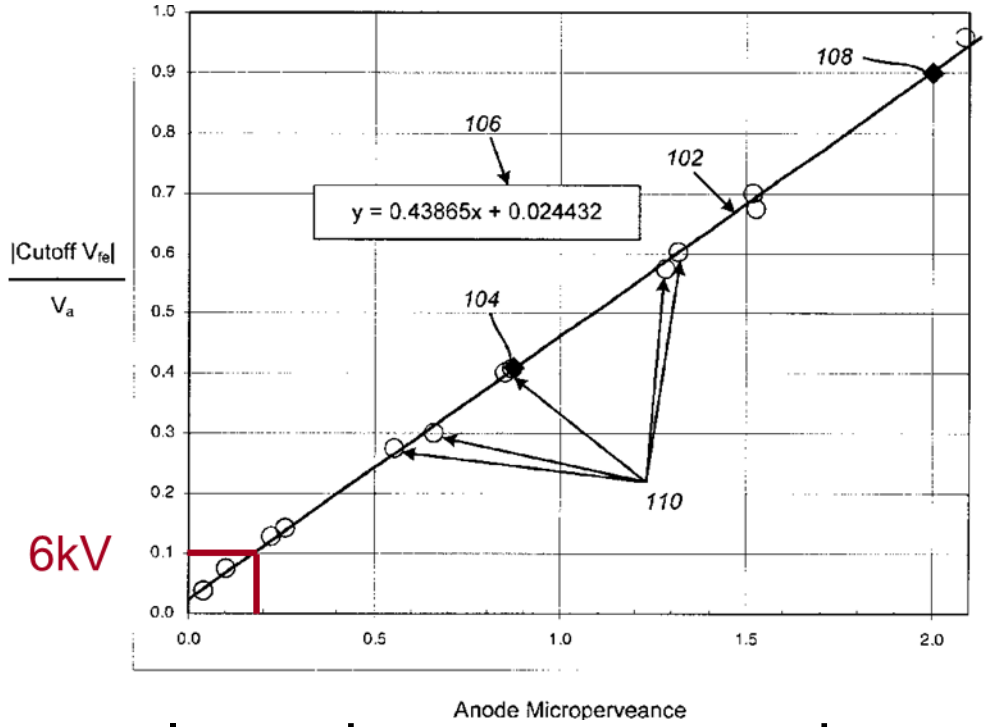
from R. Kowalczyk SLAC "RF Source Vacuum Tube Cost," May 2017

- Non-intercepting mod-anodes are very robust but require high gate voltage, adversely limiting rise time and PRF

Triode Gun
Isolated Focus Electrode (Aperture Grid)

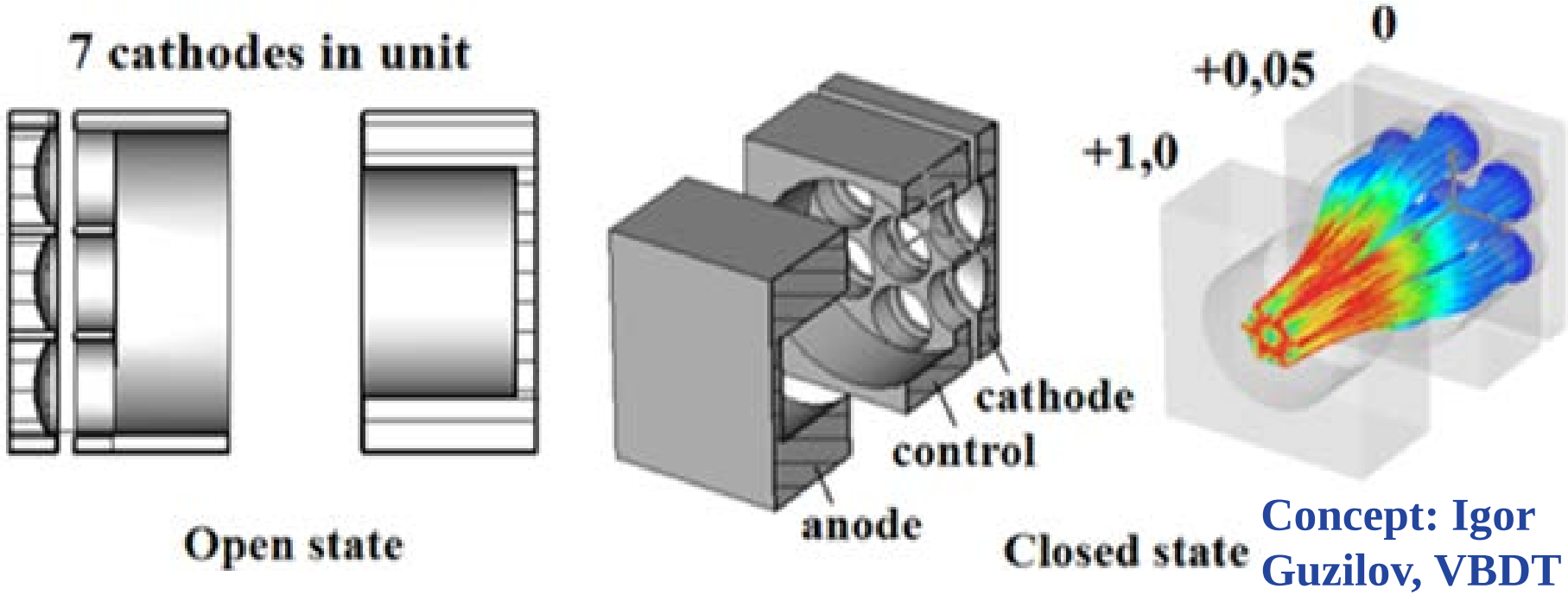


from R. Kowalczyk SLAC "RF Source Vacuum Tube Cost," May 2017



- Non-intercepting isolated focus electrodes are common in high PRF applications, but cathode size/current is limited
  - Voltage needed to cut off the beam increases with cathode diameter

Triode Gun
Gated Mini-Cathodes



Concept: Igor Guzilov, VBDT

- A single isolated focus electrode (FE) is used to modulate emission from several mini-cathodes
- Beamlets converge to create a single, high current beam

Fast Gateable Klystron Adapting a Triode Gun

- The gated mini-cathode option appears to be the best overall solution
  - Control voltage for modulating the isolated focus electrode is relatively low, allowing for fast rise times and high PRF operation
  - Toshiba E37212 requires 344 A of beam current
    - An electrode gun with a large number of small mini-cathodes, controlled by a single multi-aperture focus electrode, is needed
- High voltage stand-off considerations
  - A triode gun approach requires that the 370 kV operating voltage be applied between the cathode and grounded anode indefinitely
    - Voltage “grading” electrodes or stacked insulators likely necessary
  - Alternatively, cathode pulsing could provide 1 ms macropulse voltage to the gun, with individual pulsing via FE modulation

Fast Gateable Klystron Modulator Considerations

- A DC power supply with a “floating deck” focus electrode modulator is required
  - Architecture is similar to that used at LANSCE for the 805 MHz klystron galleries, but 370 kV E37212 operating voltage is > 4x
  - Cap bank stores energy for burst of 1 μs pulses over 1 ms period
  - LANSCE klystrons are modulated via a 70 kV mod-anode; gated mini-cathode control voltage is lower, but FEL rise time and PRF requirements are considerably more demanding
- Power supply high voltage stand-off
  - A large oil tank will be needed to hold off 370 kV indefinitely
  - Modulator to switch the isolated electrode voltage must float at high voltage, requiring very long support insulators
    - Modulator controlled via fiber optic link

Fast Gateable Klystron Other Options

- Multiple Beam Klystrons (MBKs) combine several beams in parallel to generate high levels of peak RF power
  - Each beamlet is lower perveance ($I_k/E_k^{3/2}$) reducing space charge and improving DC-RF efficiency
  - Aggreate beam current is greater, allowing higher power at lower voltage than comparable single beam klystrons; 200 kV possible
- Frequency of high peak power MBKs is currently limited to L-band; 20 MW @ 1 GHz, 10 MW @ 1.3 GHz
  - Higher order modes (HOMs) in the large diameter toroidal cavities used for the klystron resonators crowd in closer to the operating, fundamental mode as frequency is increased
  - Diameter is determined by cathode size; high current density scandate cathodes may provide a means to mitigate this problem

Fast Gateable Klystron Summary

- Retrofit existing Toshiba E37212 with gated mini-cathode triode gun design
  - Requires a 370 kV DC power supply with a floating deck pulser
  - A combination of cathode and focus electrode modulation would limit the duration of the HV across the gun to 1 millisecond, but significantly increases power supply complexity
- Multiple beam klystrons operate at lower voltage and higher efficiency
  - Architecture lends itself to the gated mini-cathode approach
  - Lower operating voltage mitigates standoff problems
  - Significant development is, however, required to solve klystron resonator HOM issues at C-band